LOW VELOCITY IMPACT RESPONSE OF LAMINATED TEXTILE COIR-ARAMIDS/EPOXY HYBRID COMPOSITES SUBJECTED TO TRANSVERSE PENETRATION LOADING

by

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Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

April 2015

ACKNOWLEDGEMENTS

First and above all, all praise is for Allah SWT, the most gracious and the most merciful, for providing me this opportunity and granting me the capability to complete what I have started. This acknowledgement is a tribute to the individuals who have assisted and inspired me in the undertaking and the completion of this research. My deepest and sincerest gratitude goes to my supervisor, Assoc. Prof. Dr. Roslan Ahmad and my co-supervisor, Prof. Ir. Dr. Mariatti Jaafar@Mustapha for their warm encouragement, inspiration, thoughtful guidance, critical comments and invaluable support throughout the duration of the thesis project.

My special appreciation is dedicated to University Tun Hussein Onn Malaysia (UTHM), Johor and the Ministry of Education Malaysia for providing the scholarship through the IPTA Academic Training Scheme (SLAI) during my period of study. I am greatly indebted to the academic and management staffs of University Sains Malaysia (USM) and UTHM, as well as the laboratory staffs who have assisted me during the experimental stages and supported me in many ways. I am also most thankful for the support of my research fellows and colleagues.

Last but not least, I would like to express my gratefulness to my beloved family for their support and understanding throughout the journey. To my parents, from the bottom of my heart, thank you for your amazing endless love and support. To my beloved husband and kids, for all that we have been through, there is nothing more I could say except thank you for the patience. All of you are my motivation to be a better person every day. I dedicate my thesis to my lovely family.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

Symbols	Descriptions
NaOH	Sodium hydroxide
E_a	Energy absorbed
E_m	Energy absorbed at maximum load point
E_p	Propagation energy
E_r	Residual energy
E_t	Total impact energy
U_{tot}	Total fracture energy
P_{peak}	Peak load
δ_{peak}	Total displacement to peak load
δ_{tot}	Maximum displacement
t_{peak}	Time at peak load
t_{tot}	Total time to penetration
DI	Ductility index
ε	Inter-yarn fabric porosity
d	diameter
m	Mass
t	Thickness
SEA_{peak}	Specific energy absorbed to peak load
SEA_{tot}	Specific total energy absorbed
wt%	Weight percentage
R^2	Coefficient of determination
Tex	Unit of measure for the linear mass density of fibres
epi	Ends per inch
ppi	Picks per inch
dpi	Dots per inch

LIST OF ABBREVIATIONS

Notations	Descriptions
AFTA	ASEAN Free Trade Area
ANOVA	Analysis of variance
ASTM	American Standard Testing Material
CFRP	Carbon fibre-reinforced polymer
DF	Degree of freedom
DOE	Design of experiment
FRP	Fibre-reinforced polymer
GFRP	Glass fibre-reinforced polymer
MS	Mean square
MW	Molecular weight
NF	Natural Fibre
PMC	Polymeric (plastic) matrix composites
PVA	Polyvinyl alcohol
SEM	Scanning electron microscope
SS	Sum of squares
TGRT	Tukey's group range test
UHMPE	Ultra high molecular weight polyethylene
UTM	Universal Testing Machine

RESPON HENTAMAN HALAJU RENDAH KE ATAS KOMPOSIT HIBRID TEKSTIL BERLAMINAT SERAT KELAPA-ARAMID/EPOKSI YANG DIKENAKAN BEBAN TUSUKAN MELINTANG

ABSTRAK

Hibrid bagi gentian sintetik dan gentian semula jadi dalam sistem komposit telah mendapat perhatian dalam bidang penyelidikan disebabkan oleh kesedaran terhadap alam sekitar. Gentian sabut kelapa diketahui mempunyai potensi yang tinggi sebagai rintangan hentaman, iaitu gentian yang rapuh membantu menyebarkan tenaga hentaman ke kawasan yang lebih luas. Fokus kajian ini ialah untuk menentukan jika terdapat sebarang penambahbaikan dalam tindak balas terhadap hentaman disebabkan oleh penggabungan serat Kevlar yang berprestasi tinggi dan gentian sabut kelapa dalam urutan susunan berlamina tertentu. Dalam kajian ini, eksperimen kuasi-statik dijalankan pada kelajuan 1.25 mm/s, dan ujian hentaman halaju rendah dijalankan dengan menggunakan penghentam berbentuk hemisfera 12.7 mm pada kelajuan yang berbeza-beza, iaitu daripada 5 m/s ke 17 m/s. Perisian Matlab digunakan untuk penyesuaian lengkung bagi data mentah, manakala ANOVA dan DOE melalui perisian Minitab digunakan bagi pemeriksaan statistik untuk menyokong hasil kajian. Kawasan komposit yang rosak dinilai menggunakan teknik analisis imej oleh peralatan pemprosesan imej daripada perisian Matlab. Analisis morfologi bagi permukaan yang retak disebabkan oleh hentaman juga diperhatikan menggunakan SEM. Pada peringkat permulaan, tindak balas hentaman optimum terhadap komposit epoksi serat kelapa bagi pelbagai reka bentuk yang diperkukuhkan, kaedah pembuatan komposit, pengubahsuaian fabrik dan ketumpatan fabrik telah ditentukan. Dapatan menunjukkan tindak balas hentaman boleh dikawal secara berkesan dengan parameter-parameter bahan yang berubah. Gentian sabut kelapa dalam bentuk struktur yang ditenun dengan ketumpatan tinggi, dirawat menggunakan larutan NaOH 6% dan dibuat menggunakan kaedah pengacuan mampatan didapati berkesan dalam menyerap dan menyebarluaskan tenaga hentaman. Spesifikasi serat kelapa tersebut kemudiannya digunakan dalam lamina hibrid. Komposit hibrid epoksi sabut kelapa/Kevlar yang mengandungi tiga lapisan luaran lamina bagi enam konfigurasi susunan yang berbeza telah dihasilkan. Komposit hibrid (dua lapisan sabut dan satu lapisan Kevlar) dikenal pasti mempunyai penyerapan jumlah tenaga khusus yang sama seperti Kevlar berlamina 100% (pada tiga lapisan). Secara kesimpulannya, komposit hibrid epoksi sabut kelapa/Kevlar menunjukkan peningkatan dalam tindak balas hentaman. Ia juga memberikan penjimatan kos bahan serta menyumbang ke arah teknologi hijau yang memberikan manfaat besar kepada industri dan komuniti.

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ABSTRACT

The hybrid of natural and synthetic fibres in a composite system has gained interest in research field due to the environmental consciousness. Coir natural fibre has been found to have a high potential as impact resistance, in which brittle fibre helps to spread the impact energy over a wider area. The focus of the study is to determine if any improvement in impact response exists as a result of combining high performance Kevlar synthetic fibre and coir natural fibre in a specified laminated stacking sequence. In this research, quasi-static experiments were conducted at the speed of 1.25 mm/s, and low velocity impact tests were conducted using a 12.7 mm hemispherical impactor at the speed varying from 5 m/s to 17 m/s. Matlab software was used for curve fitting of the raw data, whereas ANOVA and DOE via Minitab software were employed for statistical examination to support the results. The area of the damaged composite was evaluated using the image analysis technique by Matlab image processing tool. The morphology analysis of the impact fractured surfaces was also observed by SEM. At the beginning stage, the optimum impact responses of coir epoxy composites subjected to different reinforcement architecture, composite manufacturing method, fabric modification and fabric density were determined. The findings showed that the impact responses could be effectively controlled by varying material parameters. Coir fibre in the form of woven structure with dense structure, treated using 6% of NaOH solution and manufactured by compression moulding method was found to be effective in absorbing and propagating impact energy. The respective coir was then used in hybrid laminates. Coir/Kevlar epoxy hybrid composites consisted of three interply laminates layers at six different stacking configurations were developed. It was observed that the hybrid composite (two coir layers and one Kevlar layer) had equivalent specific total energy absorption as 100% Kevlar laminate (at three layers). It can be concluded that the hybrid of coir/Kevlar-epoxy laminated composites had shown an improved in impact response. It also provides cost-effective materials and contributes towards green technology which will be of great benefit to the industry and community.

CHAPTER 1

INTRODUCTION

1.0 Background

Laminated composite structure is an assembly of fibrous individual thin sheets of materials impregnated with crosslinked resin, or so called the binder, to provide required engineering properties such as in-plane stiffness, bending stiffness, strength, as well as coefficient of thermal expansion (Powell, 1994). Particularly in laminated textile fibre composite structure, layers of natural or artificial fibre structure in the form of flexible fabrics is employed and combined with the binder. Textile structures offers advantages such as subtle conformability, improved dimensional stability and deep draw shapeability are important for their efficient use in structural applications (Naik, 1994; Mallick, 1988). The orientation of fibres and stacking sequence of various textile layers can be controlled to create an extensive range of mechanical and physical properties of the composite laminate. Therefore, the uniqueness of laminated textile composite is visible as it can be tailored to fit an application (Zampaloni et al., 2007; Mallick, 1988).

Textile reinforced composite materials exhibit anisotropy. The properties may differ considerably depending on the plane or geometric axis on which they are evaluated. Textile composites are among typical high energy absorption materials. They absorb and mitigate kinetic energy effectively as they combine the valuable properties of both high performance fibres and polymer resins. Textile composites have high capability to provide protection from an impact at reduced weights.

Besides, they offer higher specific strengths (tensile strength divided by density) than their metal counterparts. Fibres used for high speed impact resistance include fibreglass, aramid fibre, woven and braided composites, as well as polyethylene fibre composites (Srivastava et al., 2011; Qiao et al., 2008).

The interest in using natural fibres (NFs) as reinforcements in polymer composites to replace synthetic fibres has increased due to the need for sustainable development and growing environmental consciousness and awareness. The most dominant use of natural fibre composites by far can be found in interior parts of the automotive industry (Anon, 2013). Figure 1.1 shows the use of natural fibres for composites in the European Automotive Industry in 2012 for the total volume of 80,000 tonnes. Coir offer advantages such as low price, unlimited and sustainable availability, low density, and low abrasive wear of processing machinery. Most importantly, coir are biodegradable, recyclable, carbon dioxide neutral and their energy can be recovered in an environmentally acceptable manner (Verma et al., 2013; Karthikeyan and Balamurugan, 2012). Coir can achieve high specific strength properties though they have poor strength properties due to low density (Begum and Islam, 2013; Satyanarayana et al., 1990). During a landfill or combustion process at the end of their life cycle, the released amount of carbon dioxide from the fibres is neutral with respect to the embraced amount during their growth. Compared to synthetic fibres, the abrasive nature of coir is much lesser. Advantages with respect to processes, material recycling and technical of composite materials in general could be reached. There is also the potential advantage of weight saving as the density of coir is much lower compared to most synthetic fibres.

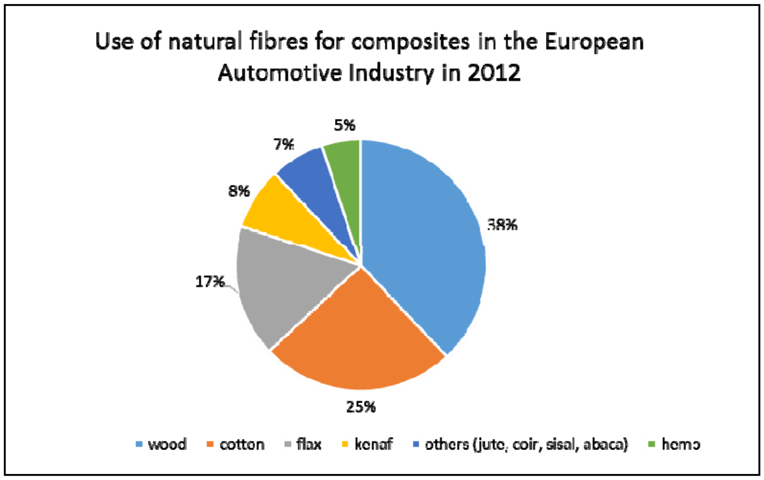

Figure 1.1: Use of natural fibres for composites in the European Automotive Industry in 2012 for the total volume of 80,000 tonnes (Anon, 2013)

NFs, at its early exposure, were used as discontinuous structure reinforcement. Until 1900s, realizing the advantages offered by continuous woven structure, efforts were made to explore its potentials (Othman and Hassan, 2013; Kamiya et al., 2000). The results displayed that continuous NF structure reinforcement had improved mechanical properties by a factor of three to four compared to the discontinuous structure (Goutianos et al., 2006). Complementary works also showed that properties like fracture toughness, ductility index and damage area of continuous reinforcement NF composite were significantly improved (Zhang et al., 2013; Kushwaha and Kumar, 2010; Liu and Hughes, 2008; Kim and Sham, 2000).

Heterogeneous and anisotropic properties exhibited by laminated textile composite have the capability to mitigate damage when impacted due to various mechanisms to transform the kinetic energy from penetrator into actions that can change the materials response, for instance plastic deformation, buckling, opening extensive crack surfaces and spreading (de-localizing) the damage zone, and other dynamic instabilities (Qiao et al., 2008). Impact resistance is defined as the ability of a material to absorb energy during fracture. The total fracture energy absorbed by a material during impact should correspond to the amount of damage in one or more modes of rupture. Higher energy absorption also indicates the toughness of the material (Iqbal and Gupta, 2008; Lu and Yu, 2003; Stronge, 2000). In aeronautical applications for instance, the key factor that affects the design allowable is the sensitivity of composite materials to low velocity. Low impact energy levels results in barely visible damage, which can lead to significant strength loses. Hence, extensive research effort is needed to explore the relationship between impact parameters, extent of failure, failure modes and residual-strength retention after impact (Wang et al., 2014; Xiao et al., 2014; Quaresimin et al., 2013; Caprino and Lopresto, 2001).

In the nature of impact energy absorption application, none of the research has proven that NF alone is able to outperform the properties of high strength and modulus of synthetic fibres. Studies conducted by Jayabal et al. (2011) had shown that the mechanical properties of woven coir/polyester composites had improved significantly with the presence of glass fibre in the composite system. Kang and Kim (2000) mentioned that energy absorption capabilities of brittle fibre composites are less than those of ductile fibre-reinforced composites. As reported by Sathishkumar et al. (2014), Jawaid and Abdul Khalil (2011) and Hariharan and Abdul Khalil (2005), hybridizing lignocellulosic fibres with a stronger and more corrosion-resistance synthetic fibre enhances the strength, stiffness, moisture and fire resistance behaviour of the lignocellulosic composite. It is in agreement with the research by Kushwaha and Kumar (2010) and Mishra et al. (2003) where they found that the